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AN ANALYSIS OF STRONG-MOTION ACCELEROMETER DATA FROM THE SAN FRANCISCO EARTHQUAKE OF MARCH 22, 1957

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ABSTRACT

The San Francisco earthquake of March 22, 1957, was recorded simultaneously by accelerometers at five United States Coast and Geodetic Survey stations in the San Francisco area. Response spectrum curves were computed from the acceleration-time records, and from these response spectrum curves the spectrum intensities have been determined. From these spectrum intensities certain conclusions are drawn as to: (1) the effects of local geology on the recorded ground motions; (2) the calculation of total energy released by the earthquake from strong-motion accelerometer records; (3) possible influence of structural dynamic behavior on the accelerations recorded in building basements, and the relationship between basement accelerations and ground accelerations; and (4) the applicability of a simplified type of strong-motion earthquake instrument for investigations of local distribution effects. A general comparison is made between the present earthquake and typical Pacific Coast earthquakes.

For the San Francisco earthquake of March 22, 1957, complete ground acceleration records were obtained from five strong-motion accelerometer stations within 20 miles of the epicenter. For the first time strong ground accelerations were simultaneously recorded at a sufficiently large number of stations to permit an investigation of the effects of local geology on the ground motions caused by a near-by strong shock to be made. In addition to these ground acceleration records, a number of records were obtained at upper floor locations in relatively tall buildings; hence, structural response calculations can be checked. The earthquake itself, although only assessed at a Gutenberg-Richter magnitude of 5.3, was so close to downtown San Francisco that structural vibrations of a considerable magnitude were set up and some structural damage occurred. Because of the special interest of this earthquake to the engineering seismologist a complete spectrum analysis of the accelerograms has been made. The relative velocity response spectrum curves and the absolute acceleration response spectrum curves of the two components of each of the five stations are given in reference 1. The purpose of the present paper is to present the results of calculations based on the response spectrum curves.

Strong-Motion accelerometer data.—In figure 1 the locations of the strong-motion accelerometer stations of the United States Coast and Geodetic Survey which recorded strong motions during the earthquake are shown. Also shown is the instrumental epicenter of the earthquake as reported by Professors Byerly and Tocher of the Seismographic Station of the University of California, Berkeley. Additional information from foreshocks and aftershocks has indicated the approximate distance along the fault zone involved in the major tearing action. With the help of this information from the Seismographic Station, an estimated center of the torn zone has been indicated on figure 1 as the approximate origin of the major disturbance. From the same data the average depth of the torn area was estimated as 5 miles. The distances shown on figure 1 are the straight-line distances from the estimated center of disturbance to the individual stations.

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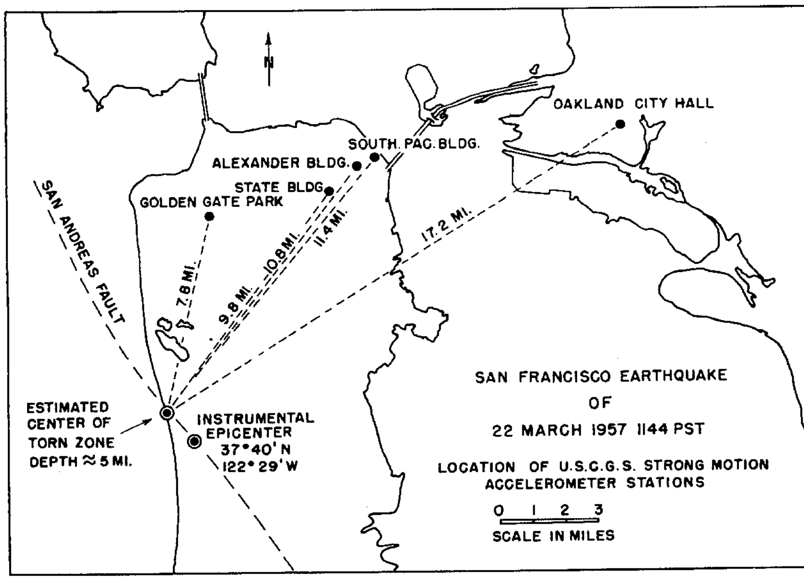

Fig. 1. Locations of epicenter and strong-motion accelerometers.

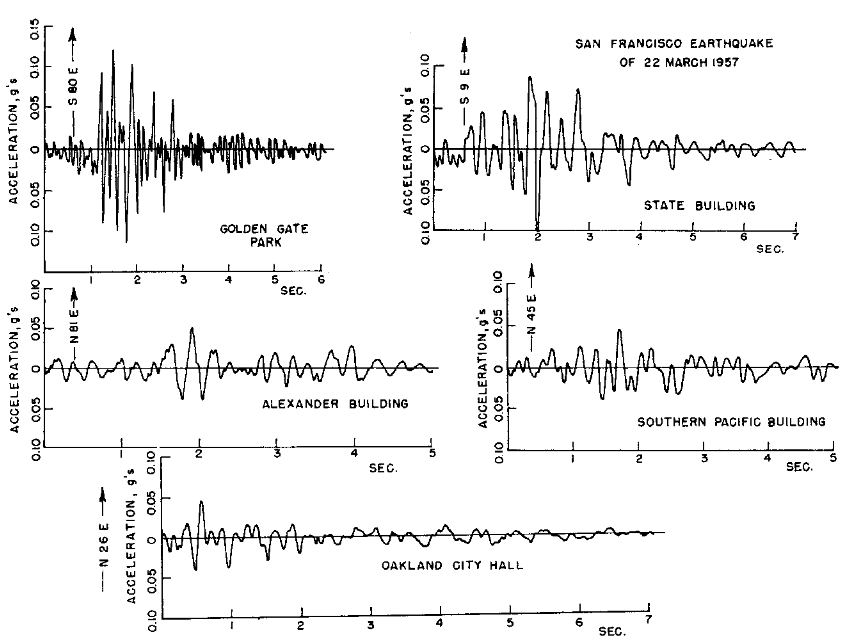

Fig. 2. Typical accelerograms at the five recording stations. Note that acceleration scales are the same, but that the time scales vary.

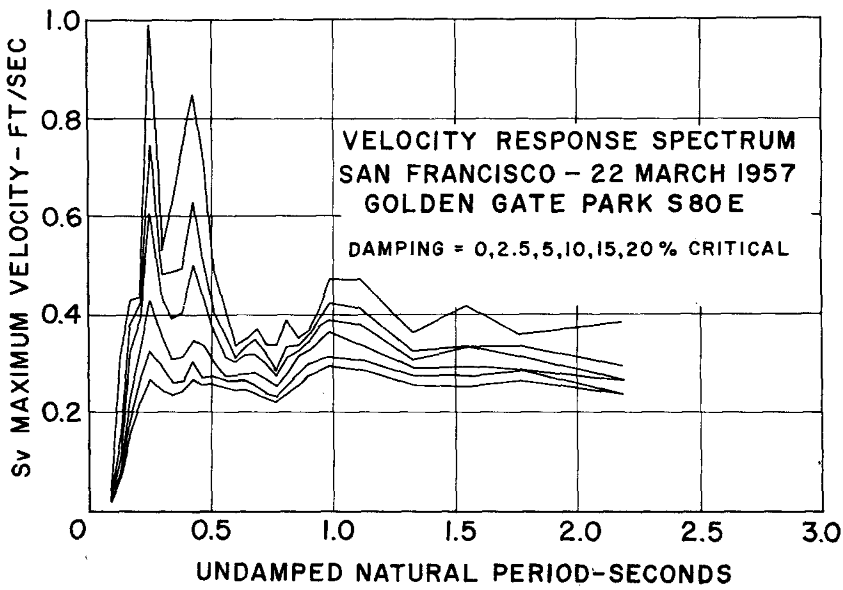

Fig. 3. Golden Gate Park S 80° E component. Maximum relative velocity response spectrum.

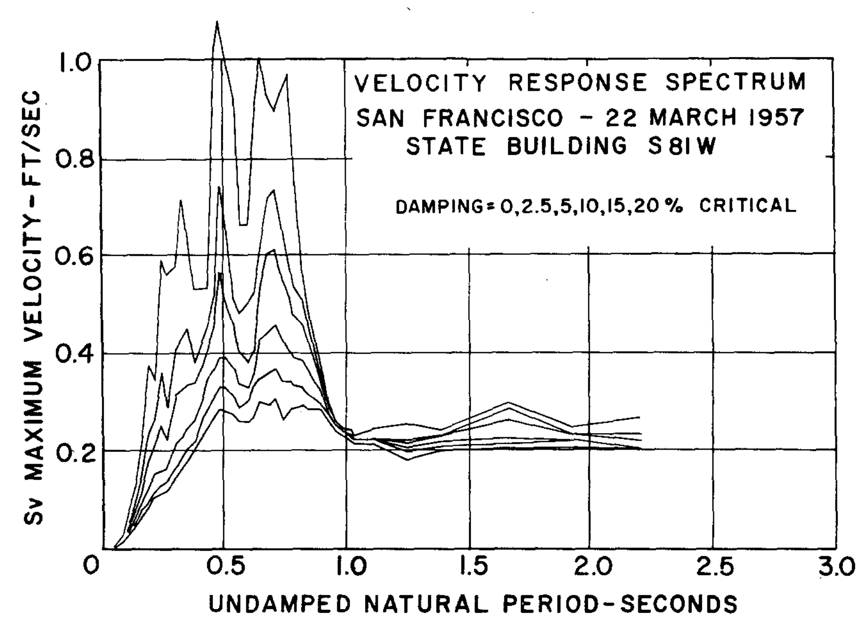

Fig. 4. State Building S 81° W component. Maximum relative velocity response spectrum.

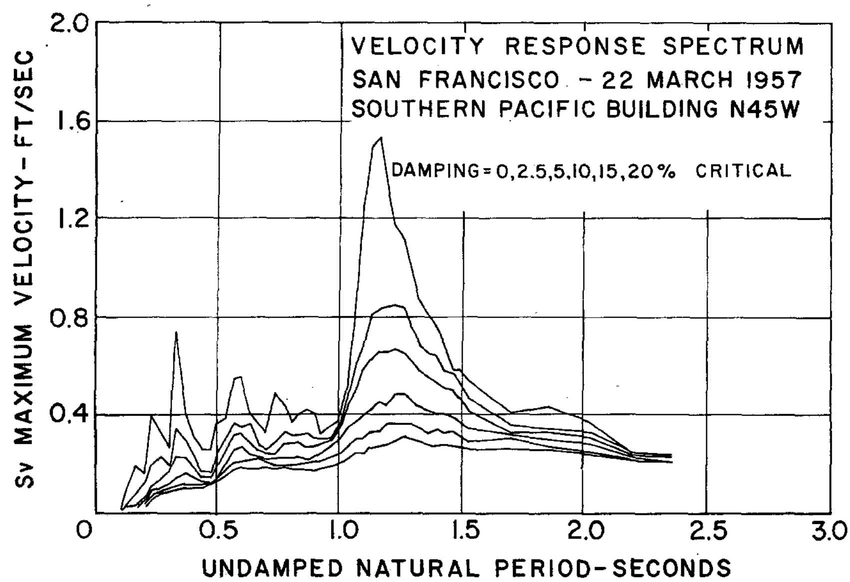

Fig. 5. Southern Pacific Building, N 45° W component. Maximum relative velocity response spectrum.

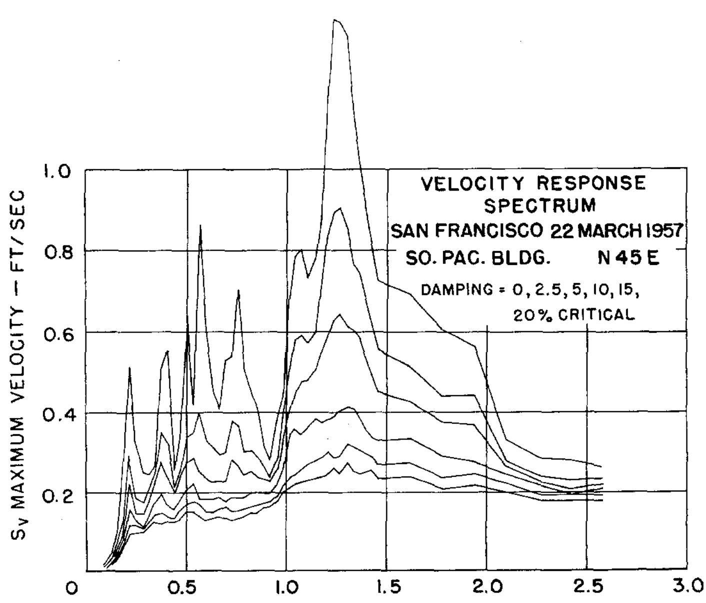

Fig. 6. Southern Pacific Building, N 45° E component. Maximum relative velocity response spectrum.

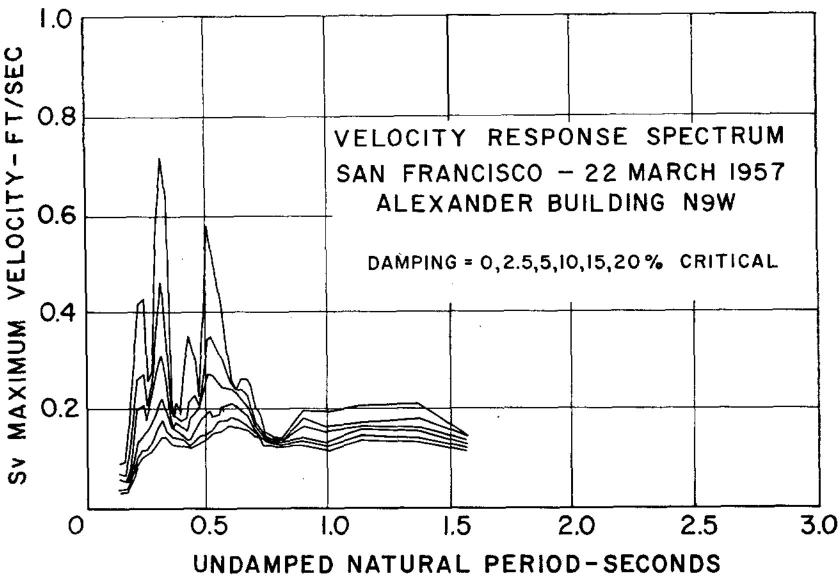

Fig. 7. Alexander Building, N 9° W component. Maximum relative velocity response spectrum.

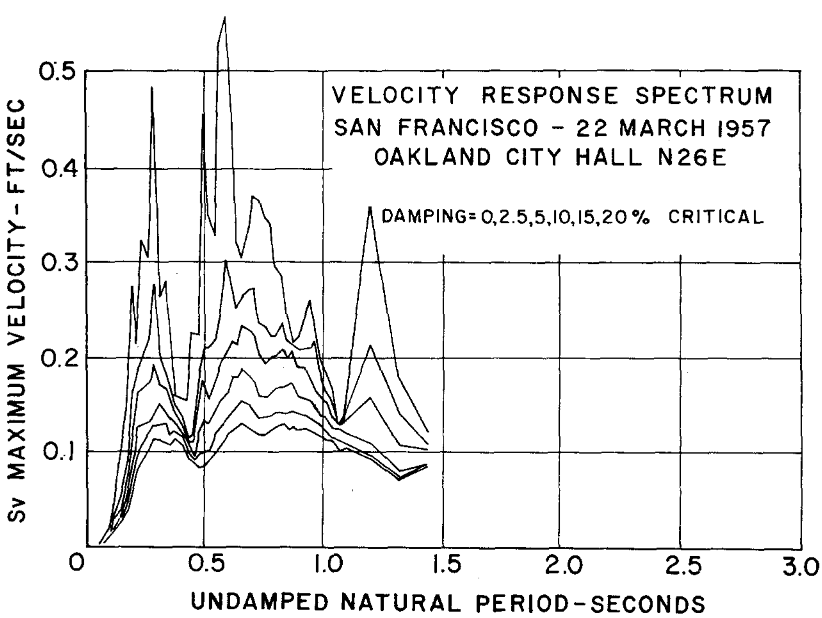

Fig. 8. Oakland City Hall, N 26° E component. Maximum relative velocity response spectrum.

In figure 2 are shown typical accelerograms from the five stations as recorded by the strong-motion accelerometers of the United States Coast and Geodetic Survey. In figures 3 to 8 some typical relative velocity response spectrum curves are shown, to indicate the nature of the basic data (references 2, 3). All the other curves from which the measurements reported below were made may be found in reference 1.

Response spectrum intensities.—As a means of making a more detailed quantitative study of the relationships between the responses at the various stations, the spectrum intensities were calculated for all the velocity response curves. The spectrum intensity S_1 is defined as the area under the relative velocity response curve

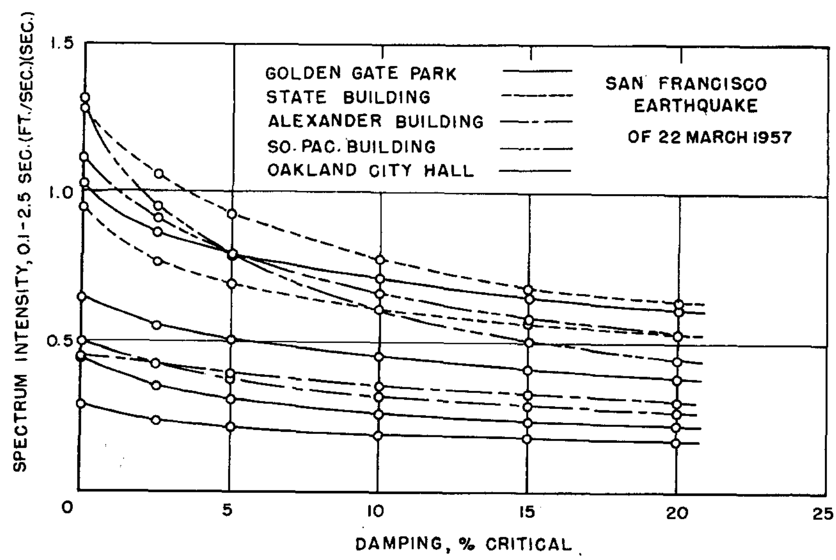

Fig. 9. Damped spectrum intensity data.

between periods of 0.1 sec. and 2.5 sec. S_1 thus measures an average spectrum value over the range of periods of structural interest. Values of S_1 for a number of typical Pacific Coast earthquakes have been computed and are given in reference 4, along with a detailed study of the correlation between S_1 and such other factors as the maximum acceleration, Modified Mercalli intensities, and Gutenberg-Richter magnitudes. One of the objects of the present study is to compare the general results from the San Francisco earthquake with the patterns established by this previous work.

In table 1 the measured values of the response spectrum intensities are summarized. The values given were determined directly from the relative velocity spectrum curves by measuring the areas under the curves between the 0.1 sec. and the 2.5 sec. ordinates. The data of table 1 are plotted in figure 9 to show the regularity of the results. There does not appear to be any simple law relating the spectrum intensity and the damping. If the exciting force were sinusoidal the spectrum intensity would be inversely proportional to the damping, whereas if the exciting force were completely random the spectrum intensity should be inversely proportional to the square root of the damping. It will be noted that the behavior of the earthquake response at small damping values is quite different from either of these limiting cases.

It should not be supposed that the behavior of figure 9 is necessarily typical of earthquake response. The time duration of the strong ground motion of this particular earthquake was approximately 3 to 4 seconds, whereas a general average for the time duration of strong-motion Pacific Coast earthquakes would be nearer 15 to 20 seconds. Since the San Francisco earthquake had a distinctly shorter time duration than most strong earthquakes, damping forces could not operate for as long a time as usual to dissipate energy from the system. As a consequence damping has a relatively smaller effect for this earthquake in reducing the response spectrum

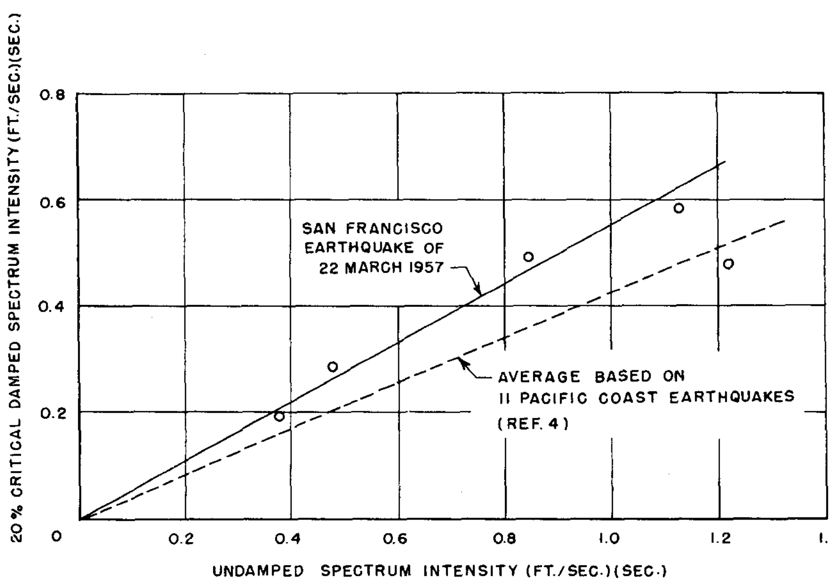

Fig. 10. Relationship between damped and undamped spectrum intensities.

curves. This may be seen from figure 10, in which the 20 per cent critical damped spectrum intensity has been plotted versus the undamped spectrum intensities, taking in each case the average of the two components for each point. Except for the last point, which should not be considered because of a special condition at that station to be discussed in a later section, the damping effects show a considerable regularity. On this same figure is shown a line representing average conditions for the group of eleven Pacific Coast earthquakes studied in reference 4. A comparison with the present earthquake shows that because of the shorter time duration the 20 per cent damped intensities are somewhat larger than they would be expected to be for a more typical earthquake.

Mean epicentral spectrum intensities.—In table 2 is a summary of the calculations based on the spectrum intensity values. In column 4 the mean spectrum intensities for the two components at each station are given, and in column 5 the epicentral spectrum intensities have been calculated, assuming an inverse-square distance relationship. It has been shown by Professors Gutenberg and Richter in reference 5 that at short distances the ground motions are approximately inversely proportional to the square of the distance from the epicenter. These experimental data indicate that the period of the waves is also involved in such a relationship, but since the distribution of periods for the present earthquake is very nearly the same for all the stations, the inverse-square relation should be adequate. The epicentral spectrum intensity S_{10} is thus calculated as:

$$S_{10} = S_1 \left[1 + \left(\frac{D}{h} \right)^2 \right]$$

where D is the epicentral distance and h is the depth. It is known that an expression of this type would not be expected to be accurate very close to the epicenter. S_{10} as

TABLE 1

Spectrum Intensities (0.1–2.5 sec.) $\left(\frac{\text{FT.}}{\text{SEC.}}\right)$ (sec.)

Station	Spectrum intensities (S_1)						
	Per cent critical damping						
	0		2.5	5	10	15	20
Golden Gate Park	S 80° E	1.038	0.865	0.795	0.711	0.648	0.605
	N 10° E	0.643	0.553	0.503	0.456	0.410	0.378
State Building	S 9° E	1.287	1.060	0.923	0.776	0.680	0.634
	S 81° W	0.954	0.765	0.695	0.606	0.558	0.525
Alexander Building	N 81° E	0.501	0.423	0.374	0.320	0.289	0.265
	N 9° W	0.449	0.425	0.396	0.351	0.324	0.300
Southern Pacific Building	N 45° E	1.318	0.951	0.783	0.605	0.500	0.440
	N 45° W	1.119	0.915	0.800	0.661	0.578	0.518
Oakland City Hall	N 26° E	0.457	0.352	0.310	0.260	0.238	0.223
	S 64° E	0.290	0.235	0.213	0.190	0.178	0.167

determined in this way should rather be considered as an extrapolated value suitable only for purposes of comparison. In the foregoing calculations the so-called "epicentral distances" are the distances to a point above the estimated center of the torn area. It is perhaps questionable that the accuracy of the data justifies a distinction between this point and the instrumental epicenter. The difference between these points is in this case not large enough to make any significant difference in the conclusions.

It will be noted in table 2 that the epicentral spectrum intensities as calculated from the various stations are by no means the same. It thus appears that local geological conditions influence the ground motions at the various stations in a significant way. An examination of the velocity response curves shows that there is a simple explanation for the relatively large intensity measured at the Southern Pacific Building. In figures 5 and 6 it will be seen that there are peaks in the response curves at periods of 1.2 sec. for the N 45° W component and at 1.3 sec. for the N 45° E component. If now one refers to the determination of the natural periods of vibration for this building, as reported in reference 6, it will be found that the fundamental periods of vibration are given as 1.13 sec. in the N 45° W direction and 1.2 sec. in the N 45° E direction. The agreement between these figures is remarkable, particularly in view of the fact that the slightly longer periods might naturally be expected for the earthquake, which undoubtedly involved considerably larger motions than the vibration tests. Reference 6 also indicates that for this building the soil conditions are "fill over mud and blue clay," and that the building stands on piles on "alluvium and made ground." It is evident that because of the special soil conditions at this station the basement of the building has a motion significantly different from the local ground motions themselves. The accelerometer thus measures the response of the building-foundation-soil system rather than the ground motion itself. This is a point of considerable importance for the interpretation of

TABLE 2

CALCULATED MAGNITUDES AND ACCELERATIONS

Station	Epicentral distance	Estimated depth	Mean spectrum intensity (S_1), zero damping	Epicentral spectrum intensity	Magnitude	Maximum acceleration	Epicentral acceleration
	mi.	mi.	ft.	ft.		g's	g's
Golden Gate Park.	6.1	5	0.841	2.10	5.1	0.125	0.31
State Building.....	8.4	5	1.121	4.30	5.5	0.105	0.40
Alexander Building	9.6	5	0.475	2.22	5.15	0.050	0.23
Southern Pacific Building........	10.1	5	1.218	6.19	5.7	0.045	0.23
Oakland City Hall.	16.4	5	0.373	4.39	5.5	0.045	0.53

strong-motion accelerometer measurements, since many of the strong-motion instruments are placed in the basements of large buildings. The only direct evidence hitherto available has been reported in reference 7, where by a comparison between accelerations measured in the basement of the Hollywood Storage Building and those measured on the ground outside it was shown that the basement essentially followed the ground motion. The present results indicate that this may not always be the case, and that a careful study of the response spectrum curves should always be made with this possibility in mind. It is interesting to note that this pronounced peak in the response spectra is not readily visible in the acceleration-time record itself (fig. 2), which is perhaps an additional reason for the calculation of the response spectrum curves. The response spectrum curves may often be expected to reveal certain features of the motion which may not otherwise be evident.

The experimentally determined vibration periods of the Alexander Building, the State Building, and the Oakland City Hall are also available in reference 6, but an examination of the response spectra at these stations does not indicate a peaking as for the Southern Pacific Building. It is thus likely that at these other stations the basement accelerometers gave a faithful picture of the ground acceleration.

If we now examine mean spectrum intensity data for the four remaining stations, it is evident that there is still a two-to-one difference in the epicentral spectrum intensities. As a possible explanation for this difference the fact that the local geology at the various stations is quite different should be considered. It is known that the

Golden Gate Park station is on rock (reference 6) whereas the Alexander Building is on about 100 ft. of alluvium (reference 8). These two stations, however, indicated about the same epicentral spectrum intensity, whereas the State Building, at an intermediate position between Golden Gate Park and the Alexander Building, showed about twice the spectrum intensity. It thus seems that no simple explanation on the basis of the over-all alluvial distribution will be entirely satisfactory, and that more complex geological factors must be involved in the differences in the measured spectral intensities.

TABLE 3

Pacific Coast Strong-Motion Earthquakes

Earthquake	Gutenberg-Richter magnitude M	Strong-motion accelerometer station	M calculated from spectrum intensity	Indicated station correction
Mar. 10, 1933	6.25	Vernon	6.13	+0.12
		Subway Terminal	6.15	+0.10
October 2, 1933	5.3	Vernon	5.3	0
		Subway Terminal	5.31	−0.01
Dec. 30, 1934	6.5	El Centro	6.54	−0.04
Oct. 31, 1935	6.0	Helena	5.70	+0.30
Sept. 11, 1938	5.5	Ferndale	5.80	−0.30
May 18, 1940	6.7	El Centro	6.58	+0.12
Feb. 9, 1941	6.6	Ferndale	6.54	+0.06
June 30, 1941	5.9	Santa Barbara	5.79	+0.11
Oct. 3, 1941	6.4	Ferndale	6.5	−0.10
Mar. 9, 1949	5.3	Hollister	5.35	−0.05
Apr. 13, 1949	7.1	Seattle	6.75	+0.35
		Olympia	7.02	+0.08
Mar. 22, 1957	5.3	Golden Gate Park	5.1	+0.2
		State Building	5.5	−0.2
		Alexander Building	5.15	+0.15
		Oakland City Hall	5.5	−0.2

The results given above are of particular interest in view of the recent investigations of Professor Gutenberg on the local effects of earthquakes (reference 9). This work shows that for the relatively small shocks recorded simultaneously on a number of instruments in the Los Angeles area there is a direct relationship between the amplitude of the ground motion and the thickness of the alluvium. The magnitudes of the amplitude ratios obtained varied somewhat with the period of the waves, showing in the Pasadena region a maximum at periods of around 1 to 2 sec., with a pronounced falling off at the lower and the higher periods. At the maximum point, amplitude ratios of 5 to 6 were not uncommon.

It is not certain to what extent the distribution of the strong motion accelerations or spectrum intensities in the San Francisco region should follow the patterns obtained by Professor Gutenberg in the Los Angeles region. The amount of data collected from the one earthquake of March 22, 1957, is of course far too limited to permit any definite conclusions in the matter. It may well be that at the relatively low periods mainly involved in the recorded strong-motion accelerations, which may be expected to be typical of the motions close to the epicenter of larger earthquakes, the amplitude ratios may be considerably less than those obtained for smaller and more distant shocks. The present tests indicate, however, that amplitude factors of 2 may not be unlikely in the San Francisco region even for fairly strong shocks.

As an additional means of comparing the measurements made at the various stations the Gutenberg-Richter magnitudes of the earthquake were calculated from the spectrum intensity values. The method follows that developed in the previous study of strong-motion earthquakes (ref. 4).

The relationship between the total energy released by an earthquake and the magnitude M is given by Professors Gutenberg and Richter in reference 10 as:

$$\log_{10} E = 9.4 + 2.14M - 0.054M^2$$

The total energy E can be expressed in terms of the epicentral spectrum intensity S_{10} as

$$E = CS_{10}^2$$

where C is a constant to be determined from experimental data. For the present purpose we shall determine the constant C so that the measured spectrum intensity of the earthquake of October 2, 1933, as recorded by the strong-motion accelerometer at Vernon, California, will lead to the Gutenberg-Richter magnitude as reported by the Seismological Laboratory of the California Institute of Technology for that earthquake. It has been shown in reference 4 that the constant fixed by this particular earthquake and station gives a good over-all fit for the series of eleven Pacific Coast earthquakes for which data were available at that time. For this October 2, 1933, earthquake the Gutenberg-Richter magnitude was 5.3, and the epicentral spectrum intensity S_{10}, extrapolated by the inverse-squares distance relationship, was 3.02 (ft/sec.)(sec.). Substituting these figures in the relationship,

$$\log_{10} CS_{10}^2 = 9.4 + 2.14 - 0.054M^2$$

we find that $C = (10)^{19.24}/9.12$, from which we obtain

$$0.054M^2 - 2.14M + (8.88 + 2\log_{10} S_{10}) = 0$$

Magnitudes calculated from this expression are tabulated in table 2.

The average magnitude calculated from the stations named, excluding the data from the Southern Pacific Building for the reasons discussed above, is 5.3. It is of interest to compare this result with that calculated from more distant stations. Data supplied by Professor C. F. Richter of the Seismological Laboratory at the California Institute of Technology give, as an average value based on six measurements at stations several hundred miles from the epicenter, the same figure of 5.3. Values of M for the six stations varied from 5.0 to 5.8, after the application of station corrections based on past recordings of numerous earthquakes.

Comparison with previous Pacific Coast earthquakes.—As a means of comparing the present earthquake with the studies of Pacific Coast earthquakes reported in reference 4, several tables have been prepared. In table 3 the magnitude data for twelve Pacific Coast earthquakes for which complete strong-motion accelerometer records are available are given. The Gutenberg-Richter magnitudes as reported by the Seismological Laboratory of the California Institute of Technology are compared with those calculated from the spectrum intensities as determined from the strong-motion accelerometer recordings. As discussed above, the constant in the energy-magnitude relationship was calculated so that agreement is obtained for the October 2, 1933, earthquake as recorded at Vernon. In the last column is shown an indicated station correction which would have to be applied to the magnitude as computed from the strong-motion accelerometer records in order to get complete agreement. The values computed from the seismological records have been taken as the standard since they are based on calculations from several stations, for which

TABLE 4
STATIONS RECORDING MORE THAN ONE STRONG-MOTION EARTHQUAKE

Strong-motion accelerometer station	Earthquake	Indicated station correction
Vernon	Mar. 10, 1933	+0.12
	Oct. 2, 1933	0
Subway Terminal	Mar. 10, 1933	+0.10
	Oct. 2, 1933	−0.01
El Centro	Dec. 30, 1934	−0.04
	May 18, 1940	+0.12
Ferndale	Sept. 11, 1938	−0.30
	Feb. 9, 1941	+0.06
	Oct. 3, 1941	−0.10

correction factors have been developed from simultaneous recordings of large numbers of earthquakes. As may be gathered from the data of the previous section on the San Francisco earthquake, however, such station corrections should be considered as applying only to average conditions. For a particular single earthquake considerable departures from average conditions might be encountered.

A glance at table 3 will show the importance of the present earthquake. Hitherto, there have been only three earthquakes for which strong ground motions have been recorded simultaneously at two strong-motion stations, and no earthquakes which have given such information at more than two stations.

In table 4 the data of table 3 are rearranged to show the indicated station corrections for those stations at which more than one strong earthquake has been recorded.

From the data of tables 3 and 4 the following conclusions can be reached: (1) any significant increase in accuracy and consistency of magnitude values as computed from the spectrum intensities will require some kind of station correction; and (2) no reasonable attempt at assigning such station corrections can be made on the basis of the very limited data now at hand. There does not appear to be much possibility of determining such station corrections from natural earthquakes recorded by the existing strong-motion accelerometers. Suitable natural earthquakes will presumably be so infrequent that centuries might pass before sufficient data could be accumulated. One possibility of determining such station corrections would be to record small natural earthquakes at the various United States Coast and Geodetic Survey stations, using techniques similar to those employed by Professor Gutenberg in the Los Angeles area. A comparison of such data with the results of simultaneously recorded strong motions, as obtained for the present earthquake, should then permit a correlation of the distribution of station responses to strong ground motions with the distributions for weaker and more distant shocks. On the basis of such a study, approximate station corrections could be established which would at least give improved information for average conditions.

Peak acceleration-magnitude relationships.—Returning now to table 2, it will be noted that there is a very erratic relationship between the spectrum intensities and the maximum recorded accelerations. In general, the accelerations for this earthquake are somewhat larger than would be expected for a shock of this magnitude. This is partly a consequence of the relatively short duration of the earthquake. Data given by Professors Gutenberg and Richter (refs. 9 and 10) show that the peak accelerations to be expected on rock for California shocks corresponding to the magnitude and distance at the Golden Gate Park record would be about 0.02 g's, whereas the recorded peak is about 0.12 g.

Approximate maximum epicentral accelerations were computed, using the inverse-square distance extrapolation as explained above. The results, as shown in table 2, indicate that the variations between the epicentral accelerations calculated from the five stations are of the same order of magnitude as the variations in the epicentral spectrum intensities, with some notable exceptions. The acceleration measured at the Southern Pacific Building is lower than might be expected from the spectrum intensity, which is of course connected with the fact that building response rather than ground motion is being measured at that station. The peak acceleration differences show about the same two-to-one ratio, however, that is reflected in the epicentral spectrum intensities.

In general, the acceleration data from this earthquake indicate that the maximum accelerations alone would be a poor indication of the effect of the earthquake on structures.

A strong-motion earthquake recorder.—In view of the small amount of strong-motion data which can be expected to be obtained from natural earthquakes with the limited number of recording accelerometers available, it has often been suggested that a much simplified instrument of the non-time-recording type should be developed. Such an instrument could perhaps be produced at a cost low enough to permit large numbers of them to be distributed in important areas. One such instrument is at present being tested at the Earthquake Engineering Research Laboratory of the California Institute of Technology. This instrument consists of a free conical pendulum of 0.75 sec. period and 10 per cent of critical damping.[1] The response of this pendulum to horizontal ground motions is traced out by a scriber on a smoked glass. Since the pendulum is free to move in any horizontal direction, the course of the ground motion in the horizontal plane is marked out, and hence the sequence of events can be followed even though no time-recording system is employed. In this way considerably more information than peak values alone can be obtained by a very simple means. This instrument should not be con-

[1] An instrument having these properties was originally recommended by the Earthquake Engineering Research Institute, and a prototype has recently been developed by the United States Coast and Geodetic Survey.

sidered as either a displacement meter or an accelerometer, but rather as a means of directly measuring one point on the response spectrum curves. The particular constants of the instrument were selected after an examination of a large number of typical earthquake response spectrum curves, with the thought of picking the one point which would be most important on the average for defining the general magnitude level. The expectation would be that a number of such instruments would be distributed in the vicinity of a time-recording strong-motion accelerometer. The recording instrument would give data from which the detailed nature of the response spectrum curves could be determined, while the simple instruments would give the local distribution of spectrum intensities.

It is of interest to determine from the data of the present earthquake how successful such a simple instrument would have been in revealing the local intensity distribution in the San Francisco region. In table 5 are shown response spectrum values for the larger component at each of the stations corresponding to a period of 0.75 sec. and a damping of 10 per cent. This is the information which would have been obtained from the simple instrument described above. While absolute numerical values cannot be directly compared with other values in tables 2 and 5, the ratios between the numerical values at the various stations should be similar to the ratios between the values of the spectrum intensities. These ratios are seen to be about the same for all the stations except the Southern Pacific Building. For this station no agreement would be expected, since the period of the simple instrument is well outside the region of the spectrum peak caused by the structural response. In fact, for this station the results obtained from the simple instrument would probably be more indicative of the ground motions than the total spectrum intensities.

TABLE 5

ANALYSIS OF DATA FOR PROPOSED SIMPLE INSTRUMENT

Station	Epicentral spectrum intensity	Gutenberg-Richter magnitude	Velocity at 0.75 sec. and 10 per cent damping	Extrapolated spectrum intensity	Gutenberg-Richter magnitude from single point
Golden Gate Park	2.10	5.1	0.22	2.0	5.1
State Building	4.30	5.5	0.45	6.9	5.8
Alexander Building	2.22	5.15	0.14	2.34	5.2
Southern Pacific Building	6.19	5.7	0.20	3.81	5.5
Oakland City Hall	4.39	5.5	0.12	4.72	5.6

Also given in table 5 are the earthquake magnitudes calculated from the data available from the single spectrum point. For this purpose the 10 per cent spectrum intensity was first calculated, assuming that the response spectrum ordinate was a constant for the period range 0.1 sec. to 2.5 sec. This 10 per cent spectrum intensity was then extrapolated to the zero damped spectrum intensity, assuming the same general relationship between spectrum intensity and damping established in reference 4. From this zero damping spectrum intensity the epicentral spectrum intensity and hence the Gutenberg-Richter magnitude could be calculated as shown above. The average value of the magnitude determined in this way is 5.4, compared with the 5.3 calculated from the more complete data obtained from the recording-type instrument. It is interesting to note that the spread of values for M determined from the single-point calculation with no station correction factors is of the same order as that obtained for the distant-station calculations.

It may thus be concluded that for this earthquake the simple instrument would have yielded results which would have been a very fair substitute for the more complete information obtained from the recording accelerometers.

Plans are now under way for the construction and installation of a number of such simple instruments, which should serve as a valuable supplement to the United States Coast and Geodetic Survey strong-motion accelerometers.

Conclusions

1) The San Francisco earthquake of March 22, 1957, was in general character typical of strong-motion Pacific Coast earthquakes, except that the time duration was considerably less than average. One consequence of the relatively short time duration was that damping did not have as large an effect in reducing peaks in the response spectrum curves as for more typical earthquakes. Another consequence was that the peak accelerations associated with this earthquake were somewhat larger than those usually found for earthquakes of this magnitude.

2) It appears that the acceleration measured in the basement of the Southern Pacific Building is not the ground acceleration, but is markedly influenced by building response. The response spectrum curves for this station show pronounced peaks corresponding with the fundamental natural periods of vibration of the building. Such peaks were not observed for the other stations, and hence the measured accelerations at the other stations may be considered as ground accelerations.

3) The epicentral spectrum intensities as calculated from the various stations indicate that the effects of local geological conditions may modify the recorded ground motions by a factor of about 2 to 1. There does not seem to be any simple correlation between magnitude of ground motion and the depth of the alluvial layer in the San Francisco region.

4) The Gutenberg-Richter magnitude of the earthquake as calculated from the averages of the spectrum intensities agreed with that determined from data obtained by the more distant seismological stations. This agreement was obtained with no station corrections applied to the individual stations, and the variations in magnitude as calculated from the various stations was not greater than usually found for the more distant stations. For improved accuracy, a station correction to allow for local geological conditions at the various strong-motion accelerometer stations may some day become feasible. It does not seem likely that such station corrections can be determined from strong-motion accelerometer recordings of natural earthquakes, because of the relatively small amount of data that can be accumulated in this way.

5) Simultaneous measurements of the small ground motions caused by frequently occurring natural earthquakes should be made at the various strong-motion accelerometer stations. A program for the San Francisco region similar to that recently conducted by Professor Gutenberg in the Los Angeles area would be of importance in establishing the effects of local geology. A comparison between the distribution patterns for strong ground motions from near-by sources and those for weaker motions from more distant shocks should be made.

6) A simplified non-time-recording strong-motion instrument which would record one point on the response spectrum would have given useful information for the present earthquake. The design parameters of 0.75 sec. period and 10 per cent of critical damping which had been suggested on the basis of past earthquake response spectrum curves were satisfactory for this earthquake. The distribution pattern of responses at the various stations which would have been determined from such simple instruments would agree with that found by the recording accelerometers, and the average magnitude calculated from such data would have been a useful approximation to that determined from more complete data. It is recommended that a large number of such simple instruments be installed.

References

1. Hudson, D. E., and G. W. Housner, "Response Spectrum Analysis of the San Francisco Earthquake of 22 March 1957," in a special report on the San Francisco earthquake to be issued by the Division of Mines, State of California.
2. Hudson, D. E., "Response Spectrum Techniques in Engineering Seismology," *Proceedings of the World Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, 1956.
3. Housner, G. W., R. R. Martel, and J. L. Alford, "Spectrum Analysis of Strong-Motion Earthquakes," *Bull. Seism. Soc. Am.*, Vol. 43, No. 2, April, 1953.
4. Housner, G. W., "Spectrum Intensities of Strong-Motion Earthquakes," *Proceedings of the Symposium on Earthquake and Blast Effects on Structures*, Earthquake Engineering Research Institute, 1952.
5. Gutenberg, B., and C. F. Richter, "Earthquake Magnitude, Intensity, Energy, and Acceleration," *Bull. Seism. Soc. Am.*, Vol. 32, No. 3, July, 1942.
6. Carder, D. S., and L. S. Jacobsen, "Vibration Observations," *Earthquake Investigations in California*, 1934–1935, Special Publication No. 201, U. S. Department of Commerce, Coast and Geodetic Survey, Washington, 1936.
7. Housner, G. W., "Interaction of Building and Ground During an Earthquake," *Bull. Seism. Soc. Am.*, Vol. 47, No. 3, July, 1957.
8. Blume, J. A., "Period Determinations and Other Earthquake Studies on a Fifteen-Story Building," *Proceedings of the World Conference on Earthquake Engineering*, Earthquake Engineering Research Institute, 1956.
9. Gutenberg, B., "Effects of Ground on Earthquake Motion," *Bull. Seism. Soc. Am.*, Vol. 47, No. 3, July, 1957.
10. Gutenberg, B., and C. F. Richter, "Earthquake Magnitude, Intensity, Energy, and Acceleration (Second Paper)," *Bull. Seism. Soc. Am.*, Vol. 46, No. 2, April, 1956.

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